INFRAMONITOR: A TOOL FOR REGIONAL INFRASOUND MONITORING

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ABSTRACT

With the recent increase of regional infrasound deployments, there is a need for tools that can be applied to networks of infrasound arrays in order to generate robust event catalogs. We present a new tool for regional infrasound monitoring that performs signal detection, association, and event location for networks of infrasound arrays. First, an algorithm for robust signal detection is presented, which utilizes an adaptive noise hypothesis, compensating for variable ambient noise. We show that the adaptive detection scheme performs significantly better than standard detection schemes in the presence of correlated noise. Next, we present a robust method for the association and location of infrasound events recorded at multiple arrays. A Matlab toolbox with a GUI interface, InfraMonitor 1.0, has been developed that incorporates this suite of algorithms for regional infrasound monitoring. An outline of the InfraMonitor 1.0 package is presented. A computer demonstration of InfraMonitor 1.0 will be available at the 2008 Monitoring Research Review meeting.

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OBJECTIVES

The objective of this work is to leverage new methodologies for regional infrasound monitoring, which have been recently developed at Los Alamos National Laboratory, by assimilating them into an integrated software package, which will be made available to the research community.

RESEARCH ACCOMPLISHED

Methodologies for regional infrasound monitoring

InfraMonitor 1.0 utilizes a new signal detection algorithm based on the F-statistic (Arrowsmith et al., 2008a, 2008b), which differs from the conventional F-detector in one key way: it adaptively accounts for real ambient noise. This adaptive approach is intuitively better since it is not based on an idealized assumption and therefore more closely matches the performance of human analysts.

An example showing the benefit of using an adaptive approach, which accounts for correlated noise (rather than assuming perfectly uncorrelated noise) is shown in Figure 1. This figure shows both conventional and adaptive F-detector results for a 15-minute record of data from the MSH1 four-element infrasound array in Washington State. During the 15-minute period analyzed, there was persistent correlated noise from a wind-farm located at a range of ~15 km from the array. Although this is quite an extreme case, due to the relatively large amplitude of the background noise source, a certain degree of correlated noise is typically present at any infrasound or seismic array. The example shows that the assumption of uncorrelated noise (made by the conventional detector) is clearly violated in this case, leading to virtually the whole record being detected. In contrast, the adaptive F-detector suitably compensates for the background noise, detecting purely transient high signal/noise ratio signals.
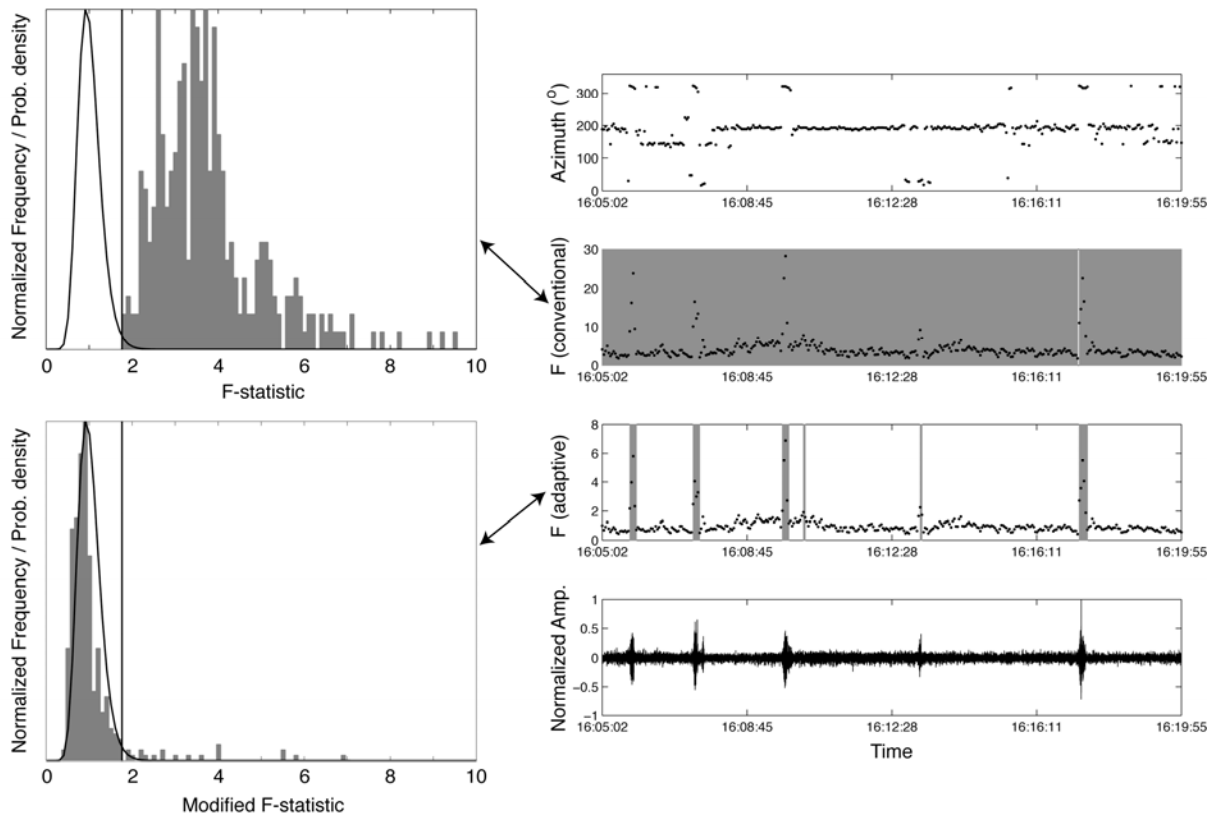

Figure 1. Example illustrating the difference between a conventional detector and the new detector outlined in this study. Histograms of the F-statistics (top left), and scaled F-statistics (bottom left), in the 15-minute time window shown. Black curves denote the appropriate theoretical F-distribution, and vertical black lines denote a p-value of 0.01.

A grid-search method for simultaneous signal association and event location has been developed and is outlined in detail by Arrowsmith et al., 2008a. The basis of the grid-search algorithm is illustrated in Figure 2. For each grid node, backazimuths, maximum interarray delay times, and minimum interarray delay times, are computed for each array (Figure 2). For each array, we have a set of observed arrival times $(\mathbf{t}_i)$ and backazimuths (Φ_i). We then loop over each grid nod, and search for sets of N arrivals (where N = number of arrays) that are consistent with predicted backazimuths (i.e., within a specified backazimuth deviation) and interarray delay times. A given event that is recorded at all N arrays may be associated with multiple grid nodes, which map out the possible event location for that event. The uncertainty in event location can be simply quantified by computing the standard deviations of the uncertainties in latitude and longitude respectively.
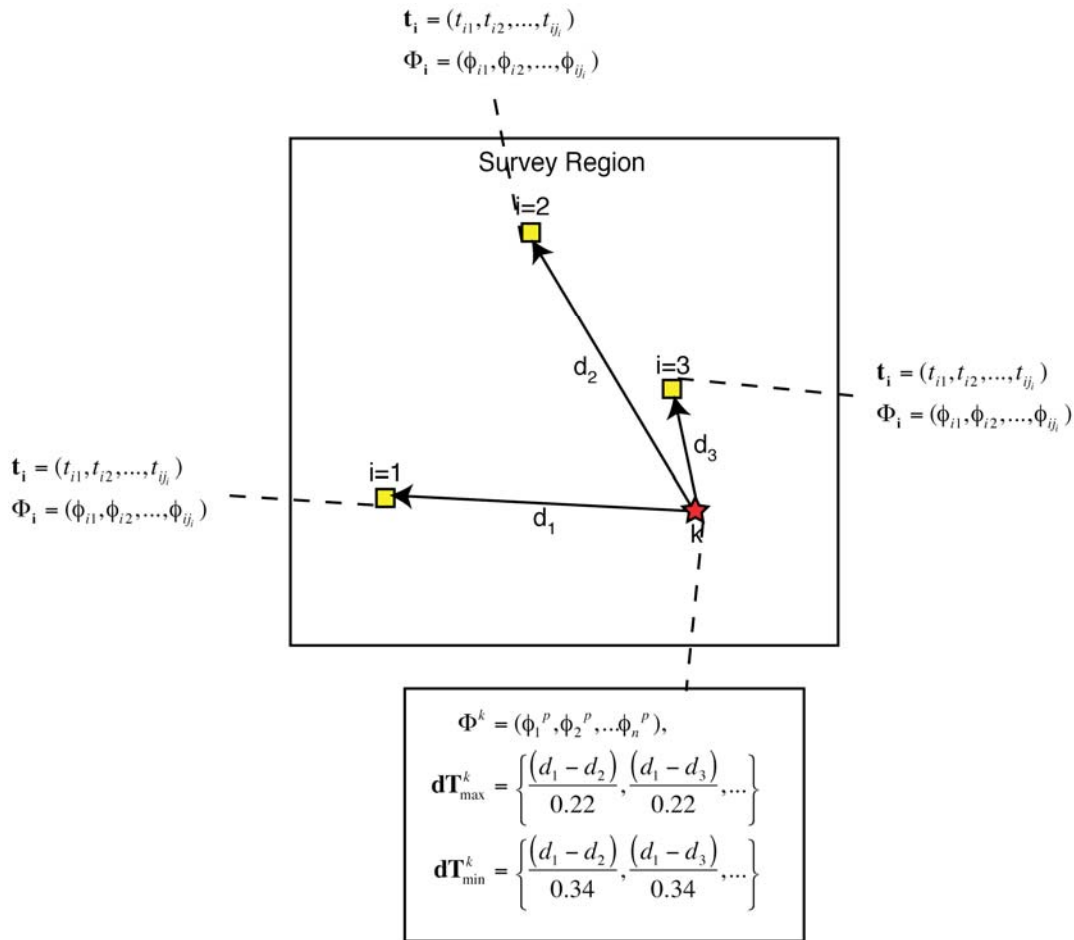

Figure 2. Schematic illustrating the grid-search method used for simultaneous signal association and event location. Yellow squares represent arrays and the red star denotes a single grid node. The upper box denotes the survey region, which is parameterized with a set of grid nodes.

Integrated Software Package

InfraMonitor 1.0 is a Matlab toolbox with a GUI interface that assimilates both the detection and the association/location algorithms outlined above. The software package is designed to seamlessly integrate the regional monitoring methodologies in order to enable the user to generate preliminary event catalogs, given waveform data from a network of infrasound arrays. This software package extends existing array-based tools such as MatSeis-InfraTool (Hart, 2004) and PMCC (Cansi, 1995) in three primary ways:

- Improved detector, which results in ~90% fewer detections from ambient noise in direct comparison tests.

- Signal Association and Event Location are fully integrated, allowing for generalized surveillance rather than a purely event-based approach.

- Command-line functionality allows for pipeline processing of large quantities of data (when the interactive interface is not practical).

Figures 3 and 4 illustrate the functionality of the InfraMonitor GUI interface for both detection and association/location of regional infrasound events.

A summary of the full InfraMonitor 1.0 processing scheme is outlined in Figure 5. The software reads array data from multiple arrays and processes the data to generate multiple detection bulletins. The full set of detection bulletins are then input into the association/location routine, which generates a preliminary event catalog for analyst review. The free parameters that must be specified in order to generate preliminary event catalogs are outlined in Table 1.

Table 1. Free parameters that must be set in InfraMonitor 1.0

| Free Parameter	Considerations
Time window	The processing time window should be set to the approximate signal durations of interest.
Overlap	An overlap between processing time windows allows us to better identify the continuous variation of slowness and backazimuth as a function of time. The limitation is computation speed. An overlap of 50% is recommended as an appropriate choice for most applications.
Adaptive window length (w)	The adaptive window length must be set long enough to obtain a sufficient sample distribution, but short enough to account for temporal variations in ambient noise. We have found that an adaptive window length of 1 hour is appropriate for typical infrasound data.
p-value	The p-value affects the numbers and signal-to-noise ratios of detections obtained. The value affects the tradeoff between the probability of detection (P_d) and the probability of false alarm P_f. A p-value of 0.01 is typical and has been found to provide a good P_d and low P_f.
Allowed backazimuth deviation $(\Delta\phi)$	The allowed backazimuth deviation should be set sufficiently large to account for the effects of wind on measured backazimuths. A value of 5° is considered appropriate, based on observational studies.
Minimum group velocity	The minimum group velocity should depend on the phase-range of interest. Following Ceplecha et al. (1998), suitable values are the following: 0.33—Lamb wave, 0.30—Tropospheric return, 0.28—Stratospheric return, 0.22—Thermospheric return.
Maximum group velocity	The maximum group velocity should depend on the phase-range of interest. Following Ceplecha et al. (1998), suitable values are the following: 0.34—Lamb wave, 0.32—Tropospheric return, 0.31—Stratospheric return, 0.24—Thermospheric return
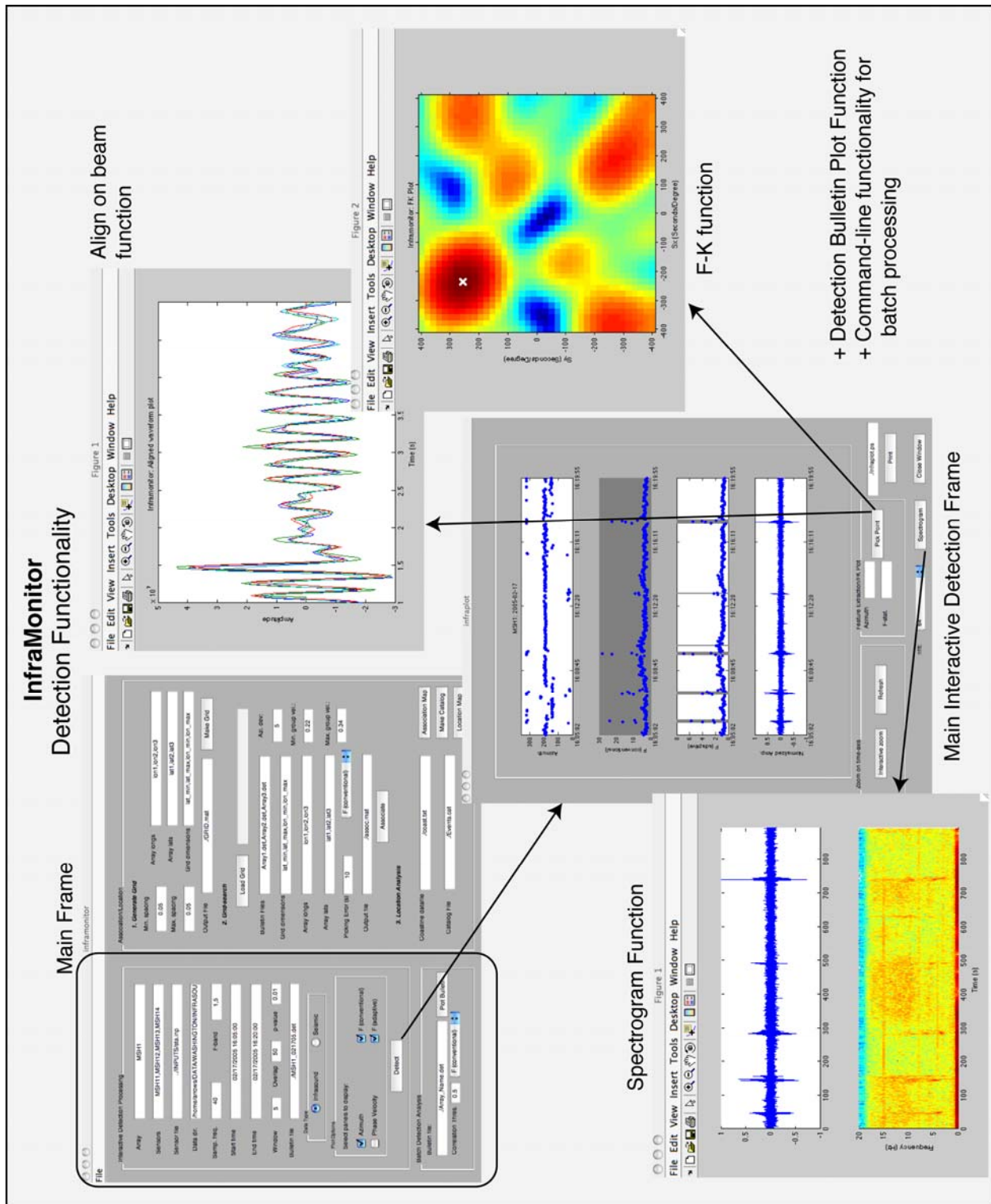
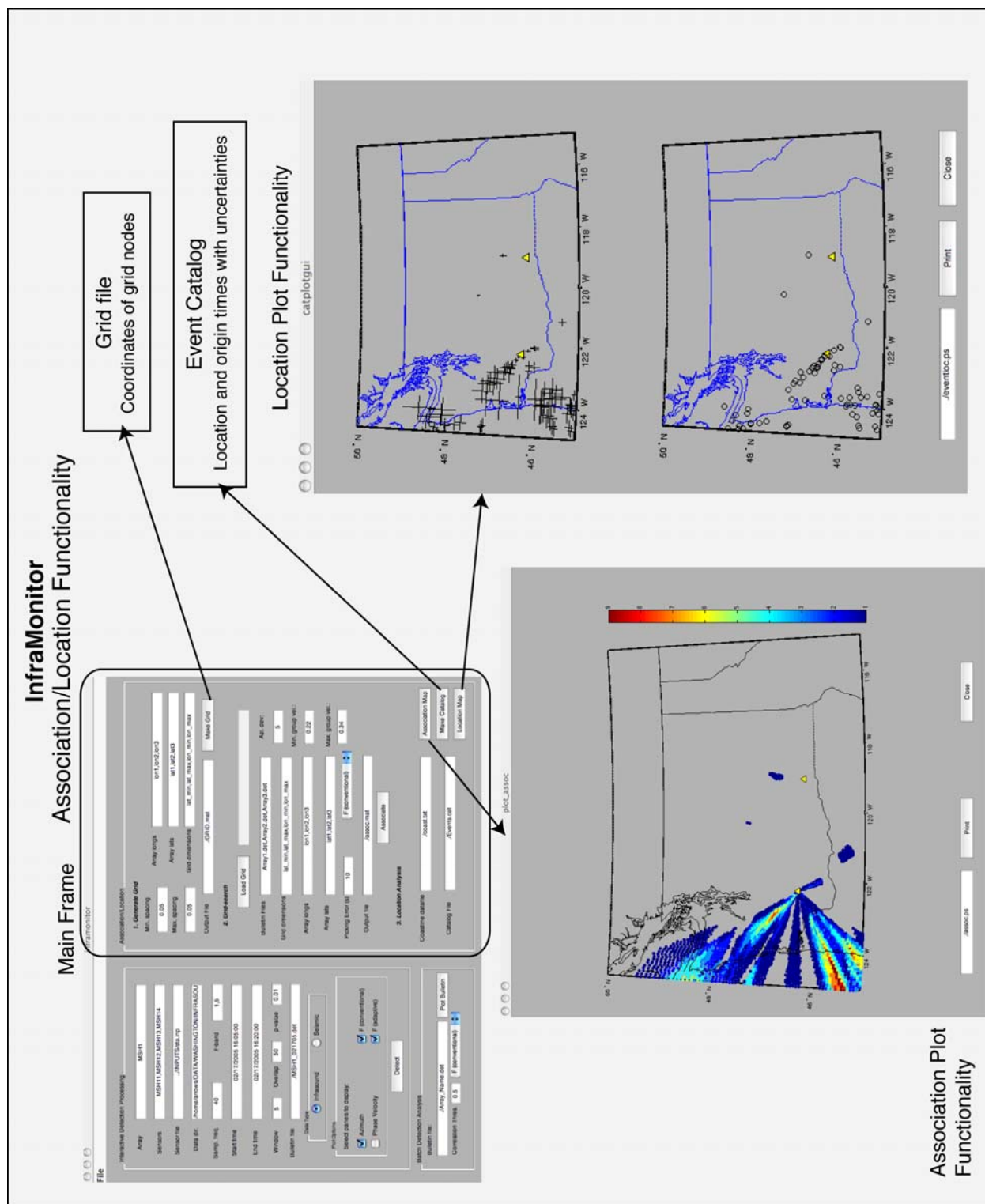**Figure 3. Screenshots showing interactive detection functionality in InfraMonitor 1.0.**

Figure 4. Screenshots showing interactive association/location functionality in InfraMonitor 1.0.
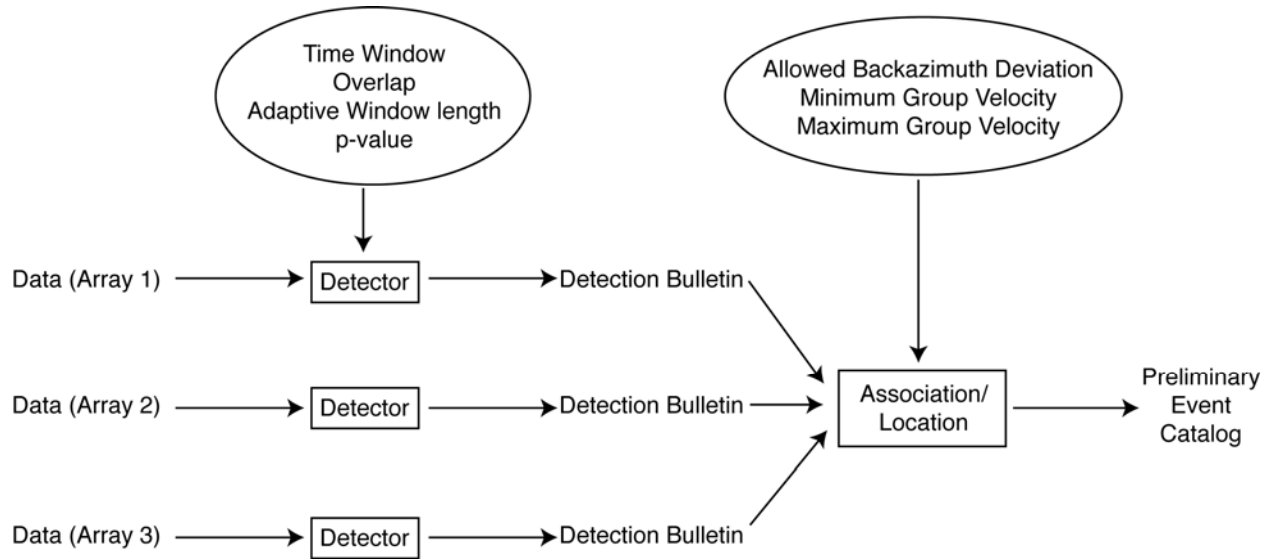
Figure 5. Flowchart illustrating the processing scheme implemented into InfraMonitor 1.0. Input/Output products are denoted by open text, algorithms are denoted by boxed text, and free parameters are denoted by text enclosed by ellipses. For simplicity, the three-array case is shown, although InfraMonitor 1.0 can be applied to networks containing ≥2 arrays.

CONCLUSIONS AND RECOMMENDATIONS

This paper introduces a new research product that has been developed at Los Alamos National Laboratory for regional infrasound monitoring. New detection, association, and location algorithms are introduced and provide the framework for the integrated software package: InfraMonitor. We review the features of InfraMonitor 1.0 and outline the processing scheme underlying the software. This software provides an invaluable tool for researchers by generating preliminary infrasonic event catalogs for further study.

REFERENCES

Arrowsmith, S. J., R. Whitaker, S. Taylor, R. Burlacu, B. Stump, M. Hedlin, G. Randall, C. Hayward, and D. ReVelle (2008a). Regional monitoring of infrasound events using multiple arrays: Application to Utah and Washington State, *Geophys. J. Int.*, submitted.

Arrowsmith, S.J., R. Whitaker, C. Katz, and C. Hayward (2008b). The F-detector revisited: An improved strategy for signal detection at seismic and infrasound arrays, *Bull. Seism. Soc. Am.*, in preparation.

Cansi, Y. (1995). An automated seismic event processing for detection and location: The P.M.C.C. method, *Geophys. Res. Lett.* 22: 1021, 1024.

Ceplecha, Z., J. Borovicka,W. G. Elford, D. O. ReVelle, R. L. Hawkes, V. Porubcan, and M. Simek (1998). Meteor phenomena and bodies, *Space Sci. Rev.* 84: 327–471.

Hart, D. (2004). Automated infrasound signal detection algorithms implemented in MatSeis – Infra Tool, Sandia report SAND2004-1889.